Brookhaven Super-Neutrino Beam Scenario

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Representing Ideas of

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Staging a Neutrino Factory

- Two feasibility studies for a **Neutrino Factory** have been performed.
  - These studies indicate a cost of 2-2.5 B$.
    - This kind of money may not be available in the current climate
  - They indicate an optimistic turn-on date of 2012.
    - We might like to do some physics before that.
- A staged approach to building a Neutrino Factory maybe desirable.
  - First Phase: Upgrade AGS to 1 MW
  - Second Phase: Build pion capture system.
  - Third Phase: Build phase rotation and part of cooling system.
  - Fourth Phase: Finish Neutrino Factory.
- Each phase can support a physics program.

First Phase Super Neutrino Beam

- Upgrade AGS to 1MW Proton Driver:

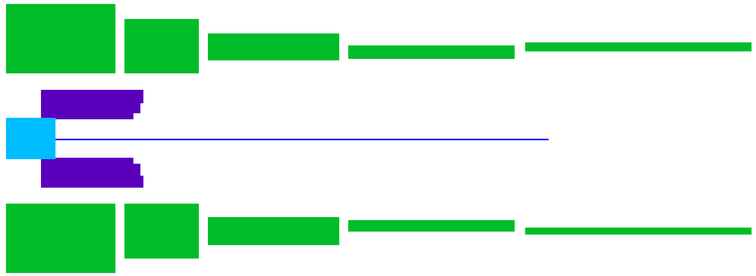
Machine	Power	Proton/Pulse	Repetition Rate	Protons/Snowmass year
Current AGS	0.23 MW ???	6×10^{13}	0.625 Hz	3.75×10^{20}
AGS Proton Driver	1 MW	1×10^{14}	2.5 Hz	2.5×10^{21}
Japan Hadron Facility	0.77 MW	3.3×10^{14}	0.29 Hz	9.6×10^{20}
Super AGS Prot Driver	4 MW	2×10^{14}	5.0 Hz	1.0×10^{22}

  – Both BNL and JHF have eventual plans for their proton drivers to be upgraded to 4 MW.

- Build Solenoid Capture System:
  – 20 T Magnet surrounding target. Solenoid field falls off to 0.1 T in 45 m.
  – This magnet focuses both π^+ and π^-. Beam will have both ν and $\bar{\nu}$
  – A solenoid is more robust than a horn magnet in a high radiation.
    - A horn may not function in the 4 MW environment.
    - A solenoid will have a longer lifetime since it is not pulsed.

Solenoid Capture

Sketch of solenoid arrangement for
Neutrino Factory



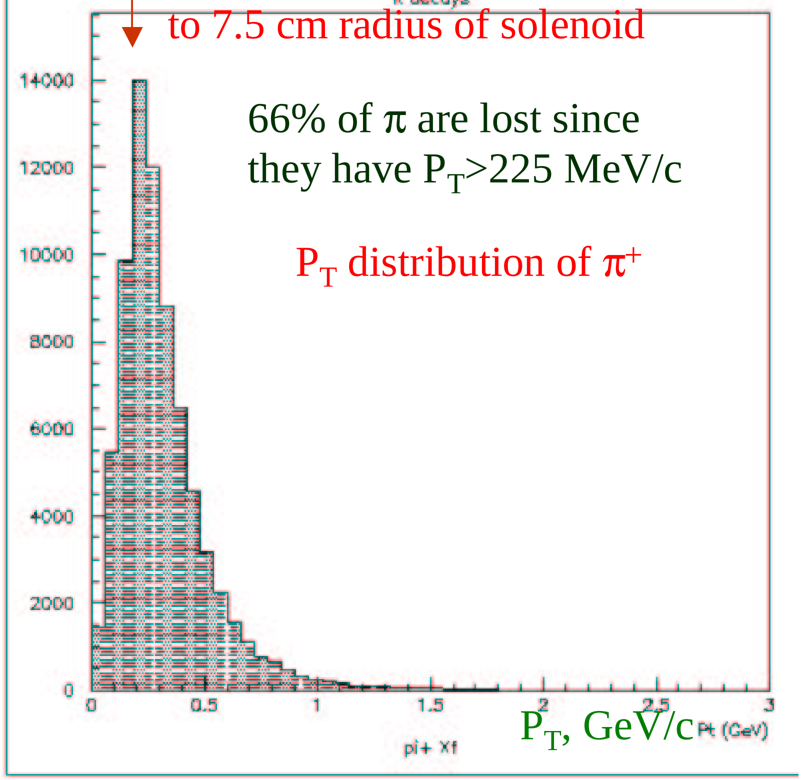
- If only ν and not $\bar{\nu}$ is desired, then a dipole magnet could be inserted between adjacent solenoids above.
- Inserting a dipole also gives control over the mean energy of the neutrino beam.

Captured Pion Distributions

P_T =225 MeV/c corresponding to 7.5 cm radius of solenoid

66% of π are lost since they have P_T>225 MeV/c

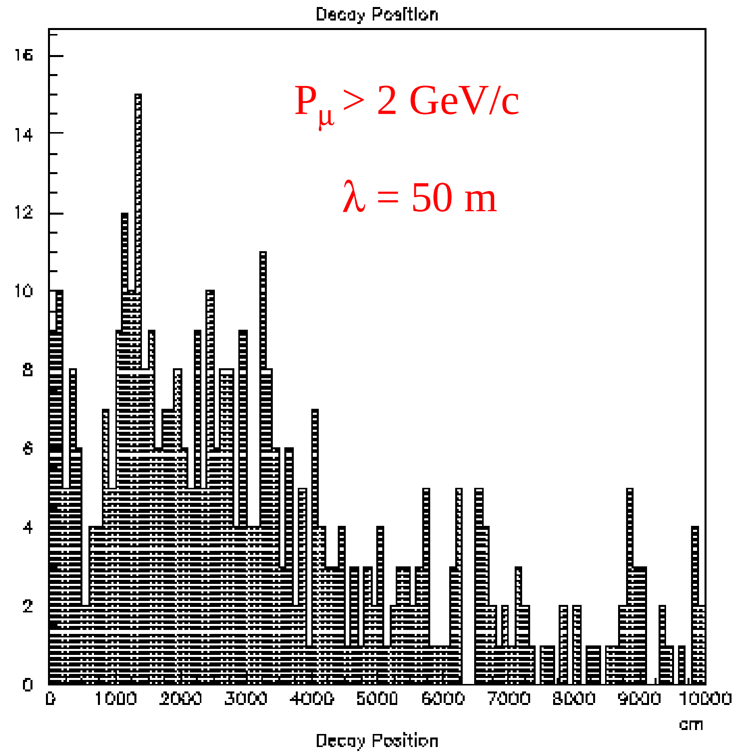
P_T distribution of π^+



P_T, GeV/c

P_μ > 2 GeV/c

λ = 50 m



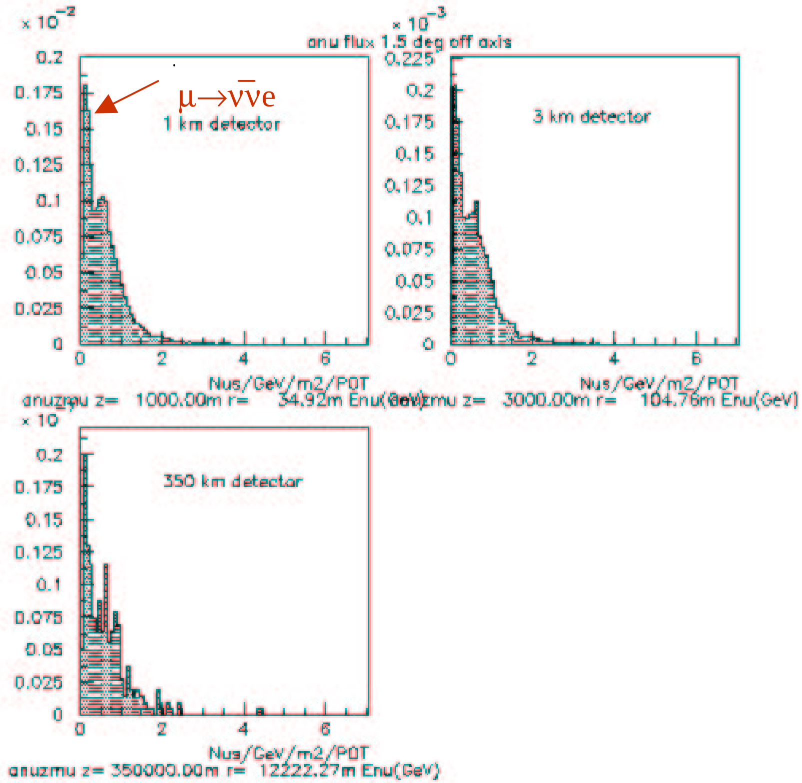
L, cm

Detector Choices

- The far detector would be placed 350 km from BNL (near Ithica, NY).
  - There are salt mines in this area. One would put the detector 2 km below ground.
- We are favoring Liquid Ar TPC similar to *Icarus*. The far detector would have 50 ktons fiducial volume (65 ktons total.)
  - Provides good electron and π^o detection.
  - The detector will sit between dipole coils to provide a field to determine the lepton charge.
- Close in 1 kton detectors at 1 km and/or 3 km.
  - 1 km detector gives ν beam alignment and high statistics for detector performance.
  - 3 km detector is far enough away that ν source is a point.

Detectors Are Placed 1.5^{o} Off ν Beam Axis

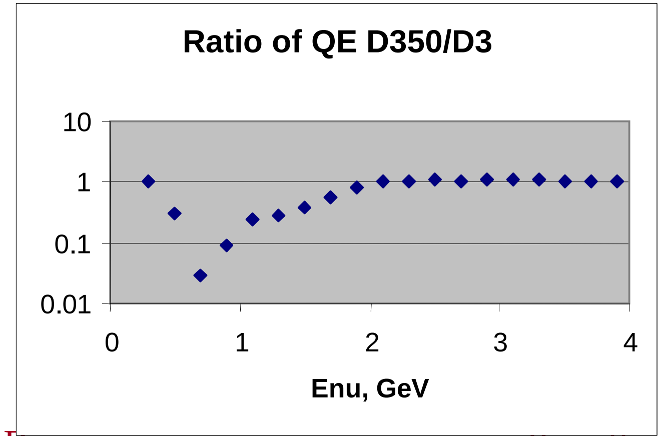
- Placing detectors at a fixed angle off axis provides a similar E_ν profile at all distances.
- It also provides a lower E_ν distribution than on axis.
- μ from π decays are captured by long solenoid channel. They provide low E_ν enhancement.
- Integrated flux at each detector:
  - Units are $\nu/m^2/POT$



Detector Position	ν_μ	Anti ν_μ	ν_e	Anti ν_e
At 1 km	1.88×10^{-2}	1.53×10^{-2}	1.75×10^{-4}	1.26×10^{-4}
At 3 km	2.07×10^{-3}	1.67×10^{-3}	1.75×10^{-5}	1.36×10^{-5}
At 350 km	1.49×10^{-7}	1.4×10^{-7}	9.27×10^{-10}	9.27×10^{-10}

Neutrino Oscillation Physics

- The experiment would look at the following channels:
  - ν_μ disappearance -- primarily $\nu_\mu \rightarrow \nu_\tau$ oscillations.
    - Sensitive to Δm_{23}^2 and θ_{23}
    - Examine ratio of $\nu n \rightarrow \mu p$ (QE) at 350 km detector to 3 km detector as a function of E_ν.
  - $\nu N \rightarrow \nu \pi^o N$ events
    - These events are insensitive to oscillation state of ν
    - Can be used for normalization.
  - ν_e appearance
    - (continued on next transparency)



ν_e Appearance Channel

- There are several contributions to $P(\nu_\mu \rightarrow \nu_e)$:
  - Solar Term: $P_{solar}=\sin^2 2\theta_{12} \cos^2\theta_{13} \cos^2\theta_{23} \sin(\Delta m^2_{sol} L/4E)$
    - This term is very small.
  - Tau Term: $P_\tau=\sin^2 2\theta_{13} \sin^2\theta_{23} \sin^2(\Delta m^2_{atm} L/4E)$
    - This is the dominant term.
  - Terms involving the CP phase δ:
    - There are both CP conserving and violating terms involving δ.
    - The CP violating term can be measured as

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} \approx \frac{\Delta m^2_{12} L}{4E_\nu} \frac{\sin 2\theta_{12}}{\sin \theta_{13}} \sin\delta$$

    - This asymmetry is larger at lower E_{ν}. This could be ~25% of the total appearance signal at the optimum E_ν
    - The 4 MW proton driver would be necessary for this asymmetry

Event Estimates Without Oscillations

- Below is shown event estimates expected from a solenoid capture system
  - The source is a 1 MW proton driver.
  - The experiment is run for 5 Snowmass years. This is the running period used in the JHF-Kamioka neutrino proposal.
  - These are obtained by integrating the flux with the appropriate cross sections.

Detector Position	$\nu_\mu n \to \mu^- p$	$\bar{\nu}_\mu p \to \mu^+ n$	$\nu N \to \nu N \pi^o$	$\nu_e n \to e^- p$	$\bar{\nu}_e p \to e^+ n$
At 1 km	2.14×10^7	5.31×10^6	3.02×10^6	2.97×10^5	71100
At 3 km	2.37×10^6	5.81×10^5	3.35×10^5	2.95×10^4	7690
At 350 km	9050	2440	1361	108	28.3

- Estimates with a 4 MW proton driver source would be four times larger.

Cosmic Ray Background

- This table shows the cosmic ray rates for a detector placed on the surface.
  - The rate reduction factors come from the E889 proposal.
  - The events shown are scaled to the 350 km detector mass and 5 Snowmass year running period.

	Muons	Neutrons
Raw Rate (kHz)	81.7	2.7
Beam Time Correlation Reduction	2.5×10^{-7}	2.5×10^{-7}
Passive/Active Shielding	0.001	0.18
Energy Cuts	0.47	0.26
Vertex and Direction Info	0.0033	0.062
Total Reduction	3.9×10^{-13}	7.2×10^{-10}
Background in 5×10^7 sec	34	2280

- The detector will be placed 2 km below ground in a mine.
  - The residual cosmic ray background would be ~0.002 events.

Backgrounds to ν_e Appearance Signal

- The largest backgrounds to the $\nu_\mu \rightarrow \nu_e$ signal are expected to be:
  - ν_e contamination in the beam.
    - This was ~1% in the capture configuration that was used in this study. It can be made smaller as I previously discussed. This could be ~0.5%
  - Neutral Current $\nu\pi^o N$ events where the π^o are misidentified as an electron.
    - If a γ from the π^o converts close to the vertex (Dalitz decay) and is asymmetric.
    - The magnetic field and dE/dx will be helpful in reducing this background. Simulation study is necessary.
    - I estimate (guess) that this background is ~0.001 of the $\nu\pi^o N$ signal.

Conclusions

- A high intensity neutrino super beam maybe an extremely effective way to study neutrino oscillations.
  - In particular the 4 MW version of the super beam may be the only way to observe CP violation in neutrino oscillations without a *Muon Ring Neutrino Factory*.
- This experiment is directly competitive with the JHF-Kamioka neutrino project.
  - Do we need two such projects? I will not answer that!
- At this point this is a *Snowmass Study*. We have only invested a few man-weeks in it.